Large Angular Convergence Scanned Beam Illumination (LACSBI): Incoherent Imaging for Conventional TEM

NIST researcher has developed a method for quantitative chemical imaging at nanometer resolution that damps coherent contrast mechanisms in CTEM imaging, thus removing the "show stopping" obstacle to its use for efficient imaging. The method involves a hybrid mode of instrument operation, in which CTEM imaging is performed while operating the microscope in STEM mode.

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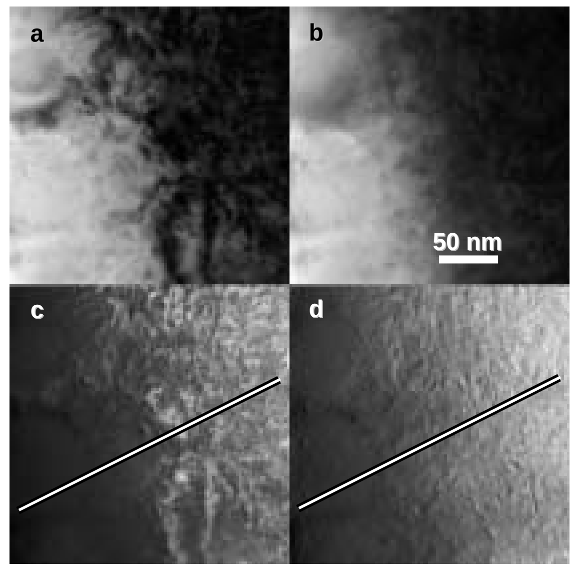
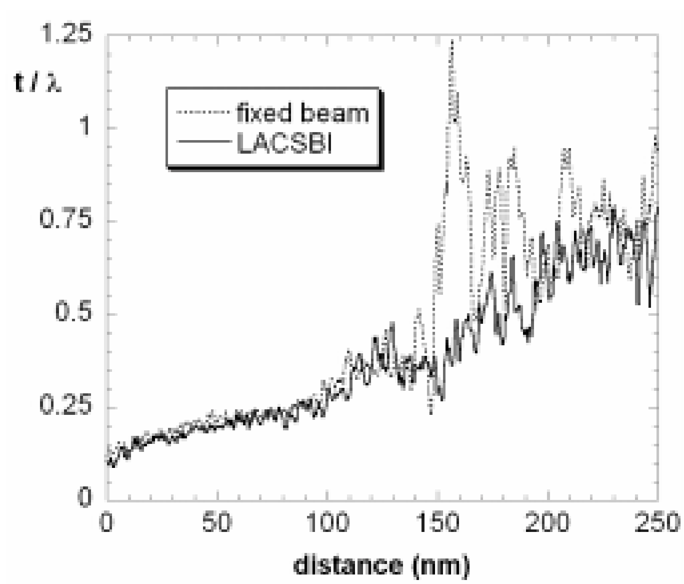
The transmission electron microscope (TEM) provides a flexible tool for metrology at spatial resolutions of a nanometer and smaller. In the conventional (CTEM) mode of instrument operation, the specimen is uniformly illuminated with a spread electron beam, and an image is formed with the microscope's objective lens, analogous to optical microscopy. In the scanning (STEM) mode, the electron beam is focused into a small probe, and an image of the specimen is formed by translating the probe across the specimen in a two-dimensional (2D) raster, and displaying the signal of a detector in a synchronous raster. Generally speaking, CTEM techniques are most efficient for [2D] imaging applications, because the many pixels comprising the image are acquired in parallel, whereas STEM techniques are best suited to [1D] profiling and [0D] point analysis, since the pixels must be acquired serially, but the outputs of multiple parallel detectors can be acquired simultaneously. For example, a 256×256-pixel hyperspectral chemical image using electron energy-loss spectroscopy (EELS) can be acquired in minutes by energy-filtered CTEM (EFTEM) using an energy range (0 to 1000 eV) that distinguishes among all elements of the periodic table; the same data acquired using the comparable STEM approach would take hours to achieve comparable statistics. Unfortunately, quantitative CTEM imaging of crystalline specimens is inhibited by diffraction effects – coherent scattering contrast that arises from the dynamical diffraction of the incident probe with atoms arranged on a crystal lattice. Since the vast majority of materials are multiphase and polycrystalline, CTEM-based techniques are unreliable for quantitative imaging studies that capture the relevant microstructure.

A method has been developed that damps coherent contrast mechanisms in CTEM imaging, thus removing the "show stopping" obstacle to efficient quantitative chemical imaging at nanometer resolution. The method involves a hybrid mode of instrument operation, in which CTEM imaging is performed while operating the microscope in STEM mode. Coherent contrast is damped by image acquisition over a range of incident beam orientations, thus "averaging out" the unwanted diffraction contrast, so that the bright-field (BF) image exhibits only weak amplitude contrast (see figure). The figure shows the mitigation of diffraction effects in LACSBI mode: (a,b) zero-loss bright-field and (c,d) EFTEM t / λ_p images acquired in (a,c) TEM fixed beam and (b,d) LACSBI modes.



Profiles corresponding to line shown in (c,d) are shown in the graph below. The damping of diffraction contrast is dramatically demonstrated in EFTEM t/λ_p mapping, where coherent contrast mechanisms provide a significant artifact, masking the smooth variation in the thickness profile of the wedge-shaped TEM specimen (see graph).



Incoherent CTEM imaging methodology will allow quantitative structural and chemical imaging of nanoscale structures, such as those needed to sustain further improvements in performance in microelectronic devices in the post-CMOS era.

Future Plans: The angular variation of the incident beam orientation in a series of fixed-beam TEM images will be explored as the basis for a hyperspectral imaging technique to perform exit-wave reconstruction (EWR), similar to through-focal series reconstruction. Such an approach can be used to damp delocalized coherent contrast and to extend the resolution of TEM imaging from the so-called point resolution (best resolution from a single, fixed-beam image) to the information limit of the instrument (limited only by incoherent aberrations). Should this approach prove successful, we should be able to demonstrate, for the first time, sub-0.1-nm imaging in both TEM and STEM modes of operation on the same instrument.

Publications:

IM Anderson, “A Method for Partially Incoherent Imaging of Crystalline Specimens in Conventional TEM,” submitted to Ultramicroscopy, 2006.

IM Anderson, “LACSBI: Incoherent Imaging for Quantitative TEM,” in preparation for Microscopy and Microanalysis 13 (Suppl. 2), 2007.